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Modelling of Strength Parameters of HVFAC Roads

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Abstract: The Concrete industry across the world is facing a challenge due to the depletion of the natural minerals used in making OPC, and it has become necessary to search for other pozzolanic materials. In research, it is found that various industrial waste materials like Fly ash, Ground Granulated Blast Furnace Slag (GGBFS), Copper Slag have pozzolanic and cementitious properties. Fly Ash is one of the best materials to use in cement concrete works. Its usage has many advantages like, Concrete of better rheology, Enhanced strength and durability, Preservation of limestone reserves, and minimizing greenhouse gas emissions.

High-Volume Fly Ash Concrete (HVFAC), due to above many advantages, came into existence, in which the use of fly ash has crossed more than 50% replacement of OPC (i.e., Cement: Fly ash is 50:50).

Strength parameters (Compressive strength, Tensile strength, and Flexural strength) of the HVFAC play a very important role during the design, construction of the concrete members, mainly the rigid pavements.

The aim of this project is to formulate Model equations for the strength parameters of the HVFAC for various water/binder ratios at different concrete ages. These models are helpful in finding out the unknown parameter by just substituting the known values in the model equations.

Keywords: Compressive strength, Tensile Strength, Flexural strength, High-volume Flyash concrete, Regression Analysis, Modelling Equation

I. INTRODUCTION

A. Need of The Day

The concrete industry across the world is facing challenges to meet the demand due to enormous infrastructure development, industrialisation and urbanisation. While making OPC, the natural minerals like lime stone, are reducing day by day, so it became necessary to research for other pozzolanic materials.

The researchers found that various industrial waste materials like Fly ash, Ground Granulated Blast Furnace Slag (GGBFS), Copper Slag are having pozzolanic and cementitious properties. Hence the Need of the day is 'Usage of Waste materials as Resource materials', to preserve the natural minerals for future generations and to protect our globe from pollution.

B. Rigid Pavements

Rigid pavements are the roadways for the transportation of motor vehicles. Their usage is there almost in all the countries across the world. Huge quantities of cement concrete are required to construct the rigid pavements. So, the usage of waste materials such as fly ash is strongly required in the possible higher proportions in making cement concrete, but not at the cost of concrete quality.

Rigid Pavement is a structure made of cement concrete (PCC or RCC or PSC) surface course with underlying base / sub-base courses. The surface course is the stiffest layer that provides majority of the strength. The base / sub-base layers are less stiffer than the top surface but make an important contribution to drainage and frost protection.

C. Fly Ash

It is a fine powder resulting from the combustion of powdered coal, transported by the flue gases of the boiler and collected in Electrostatic Precipitators (ESP).

1) *Fly Ash Availability* [18]*:* About 60% power is produced by burning coal. The coal is having very high ash content (30 - 45%), resulting in a huge quantity of ash generation. The ash generation is in millions of tons and expected to be manifold in the coming years. The modern power plants with ESP produce fly ash with good quality & low unburnt carbon, i.e., less loss on ignition, to make fly ash available for various applications.

2) *Classifications of Fly Ash:*

a) Classification as per ASTM: C-618[6]

i) *Class - F (Low Calcium Fly Ash):*

- It is produced from burning anthracite or bituminous coal.
- The CaO ratio is lower than 10%, so it is also called Low Lime Fly Ash.
- It has pozzolanic properties.

ii) *Class - C (High Calcium Fly Ash):*

- It is produced from burning lignite or sub-bituminous coal.
- The CaO ratio is higher than 10 %, so it is also called High Lime Fly Ash.
- It has cementitious properties in addition to pozzolanic properties.

b) Classification as per IS: 3812[7]*:*

i) Grade-I: It is used for incorporation in cement mortar, concrete, lime pozzolana mixture and for manufacture of Portland pozzolana cement.

ii) Grade-II: It is used for incorporation in cement mortar and concrete and in lime pozzolana mixture.

3) Standards *Supporting Fly Ash Usage in Cement Concrete:*

- IS: 456, IS:3812, IRC:68 allows the usage of fly ash.
- The latest ACI-318 has withdrawn the limits for the usage of fly ash.

4) Major *Utilization Areas of Fly Ash:*

1. Manufacture of Portland Pozzolana Cement.
2. Performance improver in Ordinary Portland Cement (OPC).
3. Partial replacement of OPC in cement concrete.
4. High-volume Fly Ash Concrete.
5. Roller Compacted Concrete used for Dam & Pavement construction.
6. Manufacture of Ash bricks and other building products.

D. Fly Ash Concrete

R.E. Davis in 1937, at California University, made research on fly ash mixing in cement concrete. This research laid the foundation for the fly ash concrete.

1) How fly ash works in fly ash concrete: Portland cement contains about 65% lime. Some of this lime becomes free and available during the hydration process. When fly ash is mixed with free lime, it reacts chemically to form additional cementitious material, improving the properties of the concrete.

2) Benefits of Using Fly Ash in Concrete:

- Improved Ultimate strength, Workability, and Durability.
- Increased Resistance to Sulphate attack, Alkali-Silica Reactivity (ASR).
- Reduced Bleeding, Shrinkage, Permeability, and Heat of hydration.
- Lowered Costs.
- Beautiful Architectural shapes, Smooth Finishing.
- Plaster mixed with fly ash eliminates defects like: Map Cracking, Drying shrinkage Cracks, De-bonding, Expansion & Popping (surface burst).

E. High Volume Flyash Concrete (HVFAC)

Fly ash is well accepted as a pozzolanic material that can be used:

- either as a component of blended Portland cements
- Or as a mineral admixture in concrete.

The dosage of fly ash is limited to 15 - 20% by mass of total cementitious material. Usually, this amount has a beneficial effect on the workability, but it is not sufficient to improve the durability to sulphate attack, alkali-silica expansion, and thermal cracking. For this purpose, larger amounts of fly ash, about 25 - 35% are being used.

Further research proved that with 50% or more cement replacement by fly ash, it is possible to produce sustainable, high-performance concrete mixes that show high workability, high ultimate strength, and high durability. Such a type of concrete mix is termed High-Volume Fly Ash Concrete (HVFAC), as per the definition of Malhotra and Mehta. (14)

1) Characteristics defining an HVFA Concrete Mix: (15)

- A minimum of 50% of fly ash of the cementitious materials is mandatory.
- Low water content, generally less than 130 kg/m^3 is mandatory.
- Cement content, generally not more than 200 kg/m^3 is desirable.
- For mixes with 28-day compressive strength ≥ 30 MPa, Slump > 150 mm, and w/b ratio around 0.3; the use of high-range water-reducing admixtures, i.e., super-plasticizers, is mandatory.
- For mixes with 28-day compressive strength < 30 MPa, Slump < 150 mm and w/b ratio around 0.4; super-plasticizers are not mandatory.
- For concrete exposed to freezing and thawing, the use of an air-entraining admixture resulting in an adequate air-void spacing factor is mandatory.

2) Beneficial Properties of HVFA Concrete over Normal Concrete:

- Easier flowability, pumpability & compatibility.
- Better surface finish.
- Slower setting time, which is useful for joint cutting and lower power-finishing times for slabs.
- Much later strength gains between 28 days and 90 days or more.
- (With HVFA concrete mixtures, the strength enhancement between 7 and 90 days often exceeds 100%; therefore, it is unnecessary to overdesign them with respect to a given specified strength.)
- Superior dimensional stability and resistance to cracking from thermal shrinkage, auto genus shrinkage, and drying shrinkage.
- After 3 to 6 months of curing, much higher Electrical resistivity and Resistance to chloride ion penetration, tested as per ASTM: C-202.
- High durability to Reinforcement corrosion, Alkali-silica expansion, and Sulfate attack.
- Better cost economy due to lower material cost and high favorable lifecycle cost.

3) Real World Applications of Fly Ash:

- In Canada, a 7-storied building at Park Lane Development in Halifax, Nova Scotia, was built with 55% high-volume fly ash concrete.
- In the US, the State of Wisconsin has been using a 60% Class-F fly ash in concrete mix since 1989.
- In the Sydney construction market, HVFA concrete has found a commercial function and has been trialed for the Sydney Olympic facilities.
- For the Crown Casino project, Connell Wagner provided highly durable and low drying shrinkage concrete for the construction of a basement of area 55,000 sq.m, which was located below the water table.
- The Jonas Salk Institute, the most famous for its architecturally exposed concrete building, was built with fly ash concrete.
- The building of the National Council for Cement & Building Material (NCCBM) at Ballabhgarh, still looks beautiful even after weathering for so many years.
- In 2013, a building slab with HVFA nano-concrete was cast in AP, India, by the well-known author-cum-researchers, Mr. Kalidas and Mrs. Bhanumathidas (the founders of the Institute for Solid Waste Research and Ecological Balance).

F. Details of Present Work

The present work consists of formulating Mathematical Model Equations for the strength parameters i.e., Compressive strength, Tensile strength, and Flexural strength at various concrete ages and with different water-binder (w/b) ratios, as mentioned below:

1) Various Compressive strength parameters at different ages and different w/b ratios.
2) Various Tensile strength parameters at different ages and different w/b ratios.
3) Various Flexural strength parameters at different ages and different w/b ratios.
4) Different combinations of Compressive strengths, Tensile strengths, & Flexural strengths at different ages and at different w/b ratios.

II. LITERATURE SURVEY

A. Mathematical Modelling

Model is a simplified description, especially a mathematical one, of a system of process, to assist calculations and predictions. Model describes the beliefs about how the world functions. In mathematical modelling, those beliefs will be formulated into the language of mathematics, to monitor the parameters.

Mathematical Model is a description of a system using concepts and language. It usually describes a system by a set of variables and a set of equations that establish relationships between the variables. Variables may be of many types: real numbers, integer numbers, Boolean values, or strings.

Mathematical Modelling is the process of developing a mathematical model. Since prehistoric times, simple models such as maps have been used. When analysing a system, engineers use a mathematical model. They build a descriptive model of the system as a hypothesis of how the system could work or try to estimate how an unforeseeable event could affect the system.

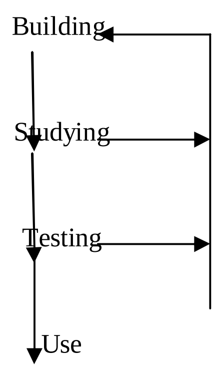
1) Objectives of Modelling:

1. Developing scientific understanding
2. Test the effect of changes in a system
3. Aid decision-making, including:
   (i) Tactical decisions by managers
   (ii) Strategic decisions by planners

2) Stages of Modelling:

1. Building,
2. Studying
3. Testing
4. Use

A pictorial representation of potential stages of modelling is as follows:



B. Choosing Mathematical Equations

Once the structure of a model has been determined, mathematical equations must be chosen to describe the system. It is worth choosing these equations carefully; they may have unforeseen effects on the behaviour of the model.

1) *Equations from the Literature:* It may be that somebody else has published an equation relating to the quantities and some other person is interested in. This provides a good starting point, but it is necessary to proceed with caution.
2) *Analogies from Physics:* Physicists have built mathematical models to describe a wide range of systems. Often, the systems can be specified precisely, making the application of mathematical equations relatively simple.
3) *Data Exploration:* Where no information exists about the form of a relationship, the only way forward is to acquire a body of data and fit equations to it. This has the advantage that the analysis will be in control.

C. Regression Analysis

Regression Analysis is a statistical tool used to examine the relationships among various variables. It quantifies the impact of changes in one or more variables (known as Independent Variables) on a variable of Interest (known as Dependent variable).

Regression models are used to predict a variable based on one or more variables. They provide a powerful tool, allowing predictions about past, present, or future events to be made using information about past or present events. These models will be employed because they are less expensive in terms of time and money to collect information for making predictions, as the event predicted will occur in the future.

In order to construct a regression model, both the information that is going to be used to make the prediction and the information that is to be predicted must be obtained from a sample of objects or individuals. The relationship between the two pieces of information is then modeled with a linear transformation. Then in the future, only the first information is necessary, and the regression model is used to transform this information into the predicted one. In other words, it is necessary to have information on both variables before the model can be constructed.

1) Terms Related to Regression Mathematical Modelling: [1]

Response Variables: Response Variables (or Dependent variables) are the variables of interest in an experiment.

Predictor Variables: Predictor Variables (or Explanatory or Independent variables) are the other variables in the experiment that affect the response and can be set or measured by the experimenter.

S (Standard Deviation): Standard Deviation is the most common measure of dispersion or how spread out the data is from the mean. As the range estimates the spread of the data (Maximum value minus Minimum value); the standard deviation estimates the average distance of individual observations from the mean. The greater the standard deviation, the greater the spread in the data. The better the equation predicts the response, the lower S is.

R^2 (R-square): R^2 is the percentage of response variable variation that is explained by its relationship with one or more predictor variables.

It is also called as Coefficient of determination or Multiple determination. R^2 is always between 0 and 100%. The higher the R^2, the better the model fits our data.

Fit (Fitted Values): Fitted Values (also called Predicted values) are the point estimates of the mean response for the given values of the predictors, factor levels, or components. In regression analysis, fitted values are essential to determining whether the model fits the data.

Residual: Residual is the difference between an observed value (y) and its corresponding fitted value ($\hat{y}$).

X:

It is the percentage of the difference between the actual value (y) and the fit value ($\hat{y}$), compared with the actual value (y).

$$x = \frac{(y-\hat{y})}{y} \; x\,100$$

III.PRE-PROJECT PHASE OF THE PAPER

A. Materials Used [20]

1) *Cement:* Ordinary Portland cement of standard brand was used, complying with its physical and chemical properties as per IS: 12269 and IS: 4031.

2) *Fly Ash:* The Fly ash of class-C, conforming to ASTM-C-618, was used in the HVFAC mix. It was collected from the thermal power plant at Vijayawada, AP.

3) *Coarse Aggregate:* 20 mm size machine crushed angular granite metal free from impurities from the local source was used. Sieve analysis results conform to IS specifications. Its other properties were:
   Specific Gravity = 2.63
   Water Absorption = 0.38%
   Bulk Density = 1490 kg/m^3
   Fineness Modulus = 7.16

4) *Fine Aggregate:* The river sand of zone-II was used as fine aggregate. The sand was free from clay, silt and organic impurities. Its other properties (IS:2386) were:
   Specific Gravity = 2.55
   Water Absorption = 1.72 %
   Fineness Modulus = 2.74

5) *Water:* The locally available potable water complied with IS standards was used.
6) *Super Plasticizer:* The super-plasticizer utilized was Endure Flowcon 04, made by Johnson. It complied with IS:9103, BS-5075, ASTM-C-494.

B. Preparation of Test Specimens [20]

1) *Mix Design:* Concrete mixes were designed as per IS: 10262, using the data obtained from the tests on Cement, Fly ash, aggregates, admixture, and water.

2) *Mixing of Concrete:* Mixing of ingredients was done as per IS: 516 in a pan mixer of 40 liters capacity. Workability of the mixes was measured and found to be medium.

3) *Casting of Specimens:* The specimens were cast in the cast iron moulds as per IS: 516. The sizes of the cast concrete specimens were as follows:
i. For Compressive strength test: 150mm x 150mm x 150mm - Cubes
ii. For Tensile strength test : 150mm Ø x 300mm long - Cylinders
iii. For Flexural strength test : 150mm x 150mm x 700mm - Beams

4) *Curing of Specimens:* The curing was done as per IS:516. The specimens were left in the molds undisturbed at room temperature for 24 hours after casting. Then the specimens were demolded, immediately transferred to the curing pond containing clean water, and cured up to the stipulated ages.

C. Strength Parameters of Test Specimens

The specimens were tested at four different ages, i.e., 28 days, 90 days, 180 days, and 360 days.

1) *Compressive Strength [10]:* The testing of the concrete for the compressive strength was done as per IS:516. The compressive strengths were calculated by dividing the maximum load applied to the specimens during the test by the cross-sectional area and expressed in MPa. The concrete cubes of size 150mm x 150mm x 150mm were used for testing.

2) *Tensile Strength (11):* The testing of the concrete specimens for the split tensile strength was done on a reliable compression machine of reliable type, along with zigs and loading strips as per IS:5816. 150mm Ø x 300mm long cylinders were used for testing. The measured splitting tensile strengths f_{ct}, of the specimens were calculated to the nearest 0.05 N/mm^2 using the formula:
$f_{ct} = 2 P/\pi\, l\, d$
where P = maximum load applied to the specimen (in Newtons)
l = length of the specimen (in mm)
d = cross-sectional dimension of the specimen (in mm)

3) *Flexural Strength [10]:* The testing of the concrete beams (Concrete beams of size 150mm x 150mm x 700mm) for flexural strength was done as per IS:516. The flexural strength of the specimen is expressed as the Modulus of Rupture f_b, which, if 'a' equals the distance (in cm) between the line of fracture and the nearer support, measured on the center line of the tensile side of the specimen, will be calculated as follows:
Case A: $f_b = (p.\ l) / (b.\ d^2)$ (when 'a' is greater than 200 mm for 150mm specimen)

Case B: $f_b = (3p.\ a) / (b.\ d^2)$ (when 'a' is less than 200 mm but greater than 170 mm for 150 mm specimen)

where p = maximum load applied to the specimen (in kg)
l = length of span, on which the specimen was supported (in cm)
b = measured width of specimen (in cm)
d = measured depth of specimen at the point of failure (in cm)
Case C: The test results will be discarded. (when a < 170 mm for 150 mm specimen)

IV. EXPERIMENTAL DATA USED FOR THIS THESIS [20]

The following data of Compressive strengths, Tensile strengths, and Flexural strengths at different w/b ratios and different ages have been used for this project (Table I, Table II, and Table III):

TABLE I
COMPRESSIVE STRENGTHS - FOR DIFFERENT W/B RATIOS & AGES

S. No.	w/b Ratio	Compressive Strengths (MPa)			
		28 days	90 days	180 days	360 days
	W/B	C28	C90	C180	C360
1	0.55	35.15	46.21	53.63	63.27
2	0.50	39.19	53.54	58.64	71.29
3	0.45	44.50	58.39	63.39	80.54
4	0.40	55.80	72.54	78.12	89.28
5	0.36	62.66	81.54	83.96	95.16
6	0.32	66.40	87.25	89.17	99.89
7	0.30	68.19	96.39	100.39	106.28
8	0.27	70.66	100.51	110.72	114.27

TABLE II
TENSILE STRENGTHS - FOR DIFFERENT W/B RATIOS & AGES

S. No.	w/b Ratio	Tensile Strengths (MPa)			
		28 days	90 days	180 days	360 days
	W/B	T28	T90	T180	T360
1	0.55	4.18	5.51	6.44	7.31
2	0.50	4.90	6.55	7.24	8.42
3	0.45	5.76	7.26	7.53	9.05
4	0.40	6.99	9.13	9.95	10.19
5	0.36	7.60	10.17	10.69	11.21
6	0.32	8.44	10.39	11.36	12.18
7	0.30	8.14	12.98	11.39	12.92
8	0.27	9.08	12.54	12.67	13.67

TABLE III
FLEXURAL STRENGTHS - FOR DIFFERENT W/B RATIOS & AGES

S. No.	w/b Ratio	Flexural Strength (MPa)			
		28 days	90 days	180 days	360 days
	W/B	F28	F90	F180	F360
1	0.55	4.16	4.70	5.24	6.30
2	0.50	4.26	5.17	6.46	7.10
3	0.45	4.34	5.43	6.60	7.70
4	0.40	4.42	5.62	6.77	8.20
5	0.36	4.61	5.74	6.89	8.28
6	0.30	5.07	5.87	7.04	8.46
7	0.27	5.42	6.22	7.46	8.96

V. FORMULATION OF MODEL EQUATIONS [1]

Model equations were formulated for the concrete strength parameters, i.e., Compressive strength, Tensile strength, and Flexural strength, at different W/B ratios and Age of the High-volume fly ash concrete.

Regression model equations were formulated by using Minitab, which is a powerful software that solves many statistical problems in the field of engineering, mathematics, statistics, economics, and sports.

A. Variables considered for Equation Formulation (shown in Table IV)

TABLE IV
VARIABLES IN THE EQUATIONS

S. No.	Variable	Description of Variable	Unit
1	W/B	Water - Binder Ratio	Unitless Constant
2	C28	Compressive Strength at 28 days	MPa
3	C90	Compressive Strength at 90 days	MPa
4	C180	Compressive Strength at 180 days	MPa
5	C360	Compressive Strength at 360 days	MPa
6	T28	Tensile Strength at 28 days	MPa
7	T90	Tensile Strength at 90 days	MPa
8	T180	Tensile Strength at 180 days	MPa
9	T360	Tensile Strength at 360 days	MPa
10	F28	Flexural Strength at 28 days	MPa
11	F90	Flexural Strength at 90 days	MPa
12	F180	Flexural Strength at 180 days	MPa
13	F360	Flexural Strength at 360 days	MPa

B. Regression Equations for the Strength Parameters [1]

B-I) Regression Analysis & Equations for Compressive Strengths, W/B & Age:

1. Regression Analysis: C28 versus W/B:

Regression equation: C28 = 110 - 139 W/B

S = 2.09191 R-Sq = 98.1%

Obs	**W/B**	**C28**(y)	**Fit**(ŷ)	**X%**
1	0.550	35.150	33.672	4.2
2	0.500	39.190	40.599	-3.6
3	0.450	44.500	47.526	-6.8
4	0.400	55.800	54.453	2.4
5	0.360	62.660	59.995	4.2
6	0.320	66.400	65.536	1.3
7	0.300	68.190	68.307	-0.2
8	0.270	70.660	72.463	-2.6

2. Regression Analysis: C90 versus W/B:

Regression equation: C90 = 154 - 201 W/B

S = 2.83867 R-Sq = 98.3%

Obs	W/B	C90	Fit	X%
1	0.550	46.21	43.08	6.8
2	0.500	53.54	53.15	0.7
3	0.450	58.39	63.22	-8.3
4	0.400	72.54	73.29	-1.0
5	0.360	81.54	81.34	0.2
6	0.320	87.25	89.40	-2.5
7	0.300	96.39	93.43	3.1
8	0.270	100.51	99.47	1.0

3. *Regression Analysis: C180 versus W/B:*

Regression equation: C180 = 158 - 199 W/B

S = 4.64874 R-Sq = 95.5%

Obs	W/B	C180	Fit	X%
1	0.550	53.63	48.63	9.3
2	0.500	58.64	58.59	0.1
3	0.450	63.39	68.55	-8.1
4	0.400	78.12	78.51	-0.5
5	0.360	83.96	86.47	-3.0
6	0.320	89.17	94.44	-5.9
7	0.300	100.39	98.42	2.0
8	0.270	110.72	104.40	5.7

4. *Regression Analysis: C360 versus W/B:*

Regression equation: C360 = 159 - 174 W/B

S = 1.69077 R-Sq = 99.2%

Obs	W/B	C360	Fit	X%
1	0.550	63.270	62.751	0.8
2	0.500	71.290	71.470	-0.2
3	0.450	80.540	80.189	0.4
4	0.400	89.280	88.908	0.4
5	0.360	95.160	95.883	-0.7
6	0.320	99.890	102.858	-3.0
7	0.300	106.280	106.345	-0.1
8	0.270	114.270	111.576	2.4

5. *Regression Analysis: C90 versus C28:*

Regression equation: C90 = - 4.89 + 1.44 C28

S = 3.22362 R-Sq = 97.8%

Obs	C28	C90	Fit	X%
1	35.1	46.21	45.58	1.4
2	39.2	53.54	51.38	4.0
3	44.5	58.39	59.01	-1.1
4	55.8	72.54	75.24	-3.7
5	62.7	81.54	85.09	-4.3
6	66.4	87.25	90.46	-3.7
7	68.2	96.39	93.03	3.5
8	70.7	100.51	96.58	3.9

6. Regression Analysis: C180 versus C28:

Regression equation: C180 = 1.78 + 1.41 C28

S = 5.54103   R-Sq = 93.6%

Obs	C28	C180	Fit	X%
1	35.1	53.63	51.33	4.3
2	39.2	58.64	57.02	2.8
3	44.5	63.39	64.50	-1.7
4	55.8	78.12	80.43	-2.9
5	62.7	83.96	90.10	-7.3
6	66.4	89.17	95.37	-6.9
7	68.2	100.39	97.89	2.5
8	70.7	110.72	101.38	8.4

7. Regression Analysis: C360 versus C28:

Regression equation: C360 = 22.1 + 1.23 C28

S = 3.64714   R-Sq = 96.3%

Obs	C28	C360	Fit	X%
1	35.1	63.27	65.23	-3.1
2	39.2	71.29	70.19	1.5
3	44.5	80.54	76.71	1.3
4	55.8	89.28	90.59	-1.5
5	62.7	95.16	99.01	-4.0
6	66.4	99.89	103.60	-3.7
7	68.2	106.28	105.80	0.4
8	70.7	114.27	108.83	-4.8

8. Regression Analysis: C90 versus C28, W/B:

Regression equation: C90 = 94.8 + 0.538 C28 - 127 W/B

S = 2.85491   R-Sq = 98.6%

Obs	C28	C90	Fit	X%
1	35.1	46.21	43.87	5.1
2	39.2	53.54	52.39	2.1
3	44.5	58.39	61.59	-5.5
4	55.8	72.54	74.01	-2.0
5	62.7	81.54	82.78	-1.5
6	66.4	87.25	89.86	-3.0
7	68.2	96.39	93.36	3.1
8	70.7	100.51	98.50	2.0

9. Regression Analysis: C180 versus C90, C28:

Regression equation: C180 = 9.53 + 1.58 C90 - 0.863 C28

S = 2.36687   R-Sq = 99.0%

Obs	C90	C180	Fit	X%
1	46	53.630	52.317	2.4
2	54	58.640	60.430	-3.0
3	58	63.390	63.522	-0.2
4	73	78.120	76.161	2.5

5	82	83.960	84.483	-0.6
6	87	89.170	90.292	-1.2
7	96	100.390	103.213	-2.8
8	101	110.720	107.601	2.8

10. Regression Analysis: C180 versus C90, C28, W/B:

Regression equation: C180 = 10.5 + 1.58 C90 - 0.868 C28 - 1.3 W/B

S = 2.64618 R-Sq = 99.0%

Obs	**C90**	**C180**	**Fit**	**X%**
1	46	53.630	52.297	2.5
2	54	58.640	60.433	-3.1
3	58	63.390	63.550	-0.2
4	73	78.120	76.158	2.5
5	82	83.960	84.472	-0.6
6	87	89.170	90.297	-1.3
7	96	100.390	103.205	-2.8
8	101	110.720	107.607	2.8

11. Regression Analysis: C360 versus C180, C90, C28:

Regression equation: C360 = 21.2 + 0.506 C180 + 0.015 C90 + 0.493 C28

S = 2.79055 R-Sq = 98.5%

Obs	**C180**	**C360**	**Fit**	**X%**
1	54	63.270	66.409	-5.0
2	59	71.290	71.046	0.3
3	63	80.540	76.141	5.5
4	78	89.280	89.379	-0.1
5	84	95.160	95.852	-0.7
6	89	99.890	100.418	-0.5
7	100	106.280	107.114	-0.8
8	111	114.270	113.621	0.6

12. Regression Analysis: C360 versus C180, C90, C28, W/B:

Regression equation: C360 = 160 + 0.499 C180 - 0.464 C90 - 0.080 C28 - 179 W/B

S = 0.983659 R-Sq = 99.9%

Obs	**C180**	**C360**	**Fit**	**X%**
1	54	63.270	63.673	-0.6
2	59	71.290	71.425	-0.2
3	63	80.540	80.095	0.5
4	78	89.280	88.954	0.4
5	84	95.160	94.325	0.9
6	89	99.890	101.157	-1.3
7	100	106.280	105.961	0.3
8	111	114.270	114.391	-0.1

B-II) Regression Analysis for Tensile Strengths, W/B & Age:

13. Regression Analysis: C360 versus C180, C90, C28, W/B:

Regression equation: T28 = 13.8 - 17.6 W/B

S = 0.229742 R-Sq = 98.6%

Obs	W/B	T28	Fit	X%
1	0.550	4.1800	4.1373	1.0
2	0.500	4.9000	5.0169	-2.4
3	0.450	5.7600	5.8966	-2.4
4	0.400	6.9900	6.7763	3.1
5	0.360	7.6000	7.4800	1.6
6	0.320	8.4400	8.1838	3.0
7	0.300	8.1400	8.5356	-4.9
8	0.270	9.0800	9.0634	0.2

14. Regression Analysis: T90 versus W/B:

Regression equation: T90 = 19.8 - 26.7 W/B

S = 0.658757 R-Sq = 95.0%

Obs	W/B	T90	Fit	X%
1	0.550	5.510	5.149	6.5
2	0.500	6.550	6.483	1.0
3	0.450	7.260	7.816	-7.6
4	0.400	9.130	9.150	-0.2
5	0.360	10.170	10.216	-0.4
6	0.320	10.390	11.283	-8.6
7	0.300	12.980	11.817	9.0
8	0.270	12.540	12.617	-0.6

15. Regression Analysis: T180 versus W/B:

Regression equation: T180 = 18.6 - 22.6 W/B

S = 0.463640 R-Sq = 96.5%

Obs	W/B	T180	Fit	X%
1	0.550	6.440	6.127	4.9
2	0.500	7.240	7.257	-0.2
3	0.450	7.530	8.387	-11.3
4	0.400	9.950	9.517	4.3
5	0.360	10.690	10.422	2.5
6	0.320	11.360	11.326	0.3
7	0.300	11.390	11.778	-3.4
8	0.270	12.670	12.456	1.7

16. Regression Analysis: T360 versus W/B:

Regression equation: T360 = 19.5 - 22.6 W/B

S = 0.258260 R-Sq = 98.9%

Obs	W/B	T360	Fit	X%
1	0.550	7.3100	7.0936	3.0

2	0.500	8.4200	8.2216	2.4
3	0.450	9.0500	9.3497	-3.3
4	0.400	10.1900	10.4777	-2.8
5	0.360	11.2100	11.3802	-1.5
6	0.320	12.1800	12.2826	-0.8
7	0.300	12.9200	12.7338	1.4
8	0.270	13.6700	13.4107	1.9

17. Regression Analysis: T90 versus T28:

Regression equation: T90 = - 0.78 + 1.47 T28

S = 0.926108 R-Sq = 90.1%

Obs	**T28**	**T90**	**Fit**	**X%**
1	4.18	5.510	5.350	2.9
2	4.90	6.550	6.405	2.2
3	5.76	7.260	7.665	-5.6
4	6.99	9.130	9.468	-3.7
5	7.60	10.170	10.362	-1.9
6	8.44	10.390	11.594	-11.6
7	8.14	12.980	11.154	14.1
8	9.08	12.540	12.532	0.1

18. Regression Analysis: T180 versus T28:

Regression equation: T180 = 0.806 + 1.29 T28

S = 0.347816 R-Sq = 98.0%

Obs	**T28**	**T180**	**Fit**	**X%**
1	4.18	6.440	6.180	4.0
2	4.90	7.240	7.105	1.9
3	5.76	7.530	8.211	-9.0
4	6.99	9.950	9.792	1.6
5	7.60	10.690	10.576	1.1
6	8.44	11.360	11.656	2.6
7	8.14	11.390	11.271	1.0
8	9.08	12.670	12.479	1.5

19. Regression Analysis: T360 versus T28:

Regression equation: T360 = 1.96 + 1.26 T28

S = 0.464209 R-Sq = 96.4%

Obs	**T28**	**T360**	**Fit**	**X%**
1	4.18	7.310	7.217	1.3
2	4.90	8.420	8.122	3.5
3	5.76	9.050	9.203	-1.7

4	6.99	10.190	10.749	-5.5
5	7.60	11.210	11.516	-2.7
6	8.44	12.180	12.572	-3.2
7	8.14	12.920	12.195	5.6
8	9.08	13.670	13.376	2.1

20. Regression Analysis: T90 versus T28, W/B:

Regression equation: T90 = 46.7 - 1.95 T28 - 60.9 W/B

S = 0.529713 R-Sq = 97.3%

Obs	T28	T90	Fit	X%
1	4.18	5.510	5.066	8.1
2	4.90	6.550	6.710	-2.4
3	5.76	7.260	8.082	-11.3
4	6.99	9.130	8.733	4.3
5	7.60	10.170	9.983	1.8
6	8.44	10.390	10.784	-3.8
7	8.14	12.980	12.587	3.0
8	9.08	12.540	12.584	-0.3

21. Regression Analysis: T180 versus T90, T28:

Regression equation: T180 = 0.932 + 0.163 T90 + 1.05 T28

S = 0.343302 R-Sq = 98.4%

Obs	T90	T180	Fit	X%
1	5.5	6.440	6.206	3.6
2	6.5	7.240	7.129	1.5
3	7.3	7.530	8.145	-8.2
4	9.1	9.950	9.737	2.1
5	10.2	10.690	10.545	1.4
6	10.4	11.360	11.460	0.9
7	13.0	11.390	11.568	-1.6
8	12.5	12.670	12.480	1.5

22. Regression Analysis: T180 versus T90, T28, W/B:

Regression equation: T180 = - 29.6 + 0.636 T90 + 2.57 T28 + 39.7 W/B

S = 0.197983 R-Sq = 99.6%

Obs	T90	T180	Fit	X%
1	5.5	6.4400	6.4664	-0.4
2	6.5	7.2400	6.9987	3.3
3	7.3	7.5300	7.6816	-2.0
4	9.1	9.9500	10.0552	-1.1
5	10.2	10.6900	10.7011	-0.1

6	10.4	11.3600	11.4172	-0.5
7	13.0	11.3900	11.4998	-0.9
8	12.5	12.6700	12.4500	1.7

23. Regression Analysis: T360 versus T180, T90, T28:

Regression equation: T360 = 2.37 - 0.083 T180 + 0.434 T90 + 0.726 T28

S = 0.306855 R-Sq = 98.9%

Obs	**T180**	**T360**	**Fit**	**X%**
1	6.4	7.310	7.265	0.6
2	7.2	8.420	8.174	3.0
3	7.5	9.050	9.083	-0.4
4	9.9	10.190	10.589	-4.0
5	10.7	11.210	11.423	-1.9
6	11.4	12.180	12.073	0.9
7	11.4	12.920	12.978	-0.4
8	12.7	13.670	13.364	2.2

24. Regression Analysis: T360 versus T180, T90, T28, W/B:

Regression equation: T360 = 47.8 + 1.03 T180 - 0.468 T90 - 2.77 T28 - 60.4 W/B

S = 0.191541 R-Sq = 99.7%

Obs	**T180**	**T360**	**Fit**	**X%**
1	6.4	7.3100	7.1305	2.4
2	7.2	8.4200	8.4963	-0.9
3	7.5	9.0500	9.1015	-0.6
4	9.9	10.1900	10.3427	-1.5
5	10.7	11.2100	11.3473	-1.2
6	11.4	12.1800	12.0267	1.3
7	11.4	12.9200	12.8831	0.3
8	12.7	13.6700	13.6219	0.3

B-III) Regression Analysis for Flexural Strengths, W/B & Age:

25. Regression Analysis: F28 versus W/B:

Regression equation: F28 = 6.32 - 4.22 W/B

S = 0.186470 R-Sq = 86.6%

Obs	**W/B**	**F28**	**Fit**	**X%**
1	0.550	4.1600	3.9967	3.9
2	0.500	4.2600	4.2076	1.2
3	0.450	4.3400	4.4186	-1.8
4	0.400	4.4200	4.6295	-4.7

5	0.360	4.6100	4.7983	-4.1
6	0.320	*	4.9670	*
7	0.300	5.0700	5.0514	0.4
8	0.270	5.4200	5.1779	4.5

 # 7 cases used, 1 case contains missing value

26. Regression Analysis: F90 versus W/B:

Regression equation: F90 = 7.44 - 4.70 W/B

S = 0.120826 R-Sq = 95.0%

Obs	W/B	F90	Fit	X%
1	0.550	4.7000	4.8510	-3.2
2	0.500	5.1700	5.0860	1.6
3	0.450	5.4300	5.3209	2.0
4	0.400	5.6200	5.5559	1.1
5	0.360	5.7400	5.7438	0.1
6	0.320	*	5.9318	*
7	0.300	5.8700	6.0257	-2.6
8	0.270	6.2200	6.1667	0.8

 # 7 cases used, 1 case contains missing value

27. Regression Analysis: F180 versus W/B:

Regression equation: F180 = 9.10 - 6.10 W/B

S = 0.331155 R-Sq = 81.1%

Obs	W/B	F180	Fit	X%
1	0.550	5.240	5.748	-9.7
2	0.500	6.460	6.053	6.3
3	0.450	6.600	6.358	3.7
4	0.400	6.770	6.663	1.6
5	0.360	6.890	6.907	-0.2
6	0.320	*	7.151	*
7	0.300	7.040	7.273	-3.3
8	0.270	7.460	7.456	0.0

 # 7 cases used, 1 case contains missing value

28. Regression Analysis: F360 versus W/B:

Regression equation: F360 = 11.3 - 8.49 W/B

S = 0.259296 R-Sq = 93.1%

Obs	W/B	F360	Fit	X%
1	0.550	6.3000	6.6207	-5.1
2	0.500	7.1000	7.0450	0.8
3	0.450	7.7000	7.4693	3.0

4	0.400	8.2000	7.8935	3.7
5	0.360	8.2800	8.2329	0.6
6	0.320	*	8.5723	*
7	0.300	8.4600	8.7420	-3.3
8	0.270	8.9600	8.9966	-0.4

 # 7 cases used, 1 case contains missing value

29. Regression Analysis: F90 versus F28:

Regression equation: F90 = 1.20 + 0.941 F28

S = 0.252987 R-Sq = 78.3%

Obs	F28	F90	Fit	X%
1	4.16	4.7000	5.1110	-8.7
2	4.26	5.1700	5.2051	-0.7
3	4.34	5.4300	5.2804	2.7
4	4.42	5.6200	5.3556	4.7
5	4.61	5.7400	5.5344	3.6
6	*	*	*	*
7	5.07	5.8700	5.9671	-1.6
8	5.42	6.2200	6.2964	-1.2

 # 7 cases used, 1 case contains missing value

30. Regression Analysis: F180 versus F28:

Regression equation: F180 = 1.23 + 1.17 F28

S = 0.471944 R-Sq = 61.7%

Obs	F28	F180	Fit	X%
1	4.16	5.240	6.107	-16.5
2	4.26	6.460	6.225	3.6
3	4.34	6.600	6.319	4.3
4	4.42	6.770	6.413	5.3
5	4.61	6.890	6.635	3.7
6	*	*	*	*
7	5.07	7.040	7.175	-1.9
8	5.42	7.460	7.586	-1.7

 # 7 cases used, 1 case contains missing value

31. Regression Analysis: F360 versus F28:

Regression equation: F360 = 0.37 + 1.62 F28

S = 0.541611 R-Sq = 70.1%

Obs	F28	F360	Fit	X%
1	4.16	6.300	7.124	-13.1
2	4.26	7.100	7.287	-2.6

3	4.34	7.700	7.416	3.7
4	4.42	8.200	7.546	8.0
5	4.61	8.280	7.855	5.1
6	*	*	*	0.0
7	5.07	8.460	8.602	-1.7
8	5.42	8.960	9.170	-2.3

 # 7 cases used, 1 case contains missing value

32. Regression Analysis: F90 versus F28, W/B:

Regression equation: F90 = 8.58 - 0.182 F28 - 5.46 W/B

S = 0.129680 R-Sq = 95.4%

Obs	**F28**	**F90**	**Fit**	**X%**
1	4.16	4.7000	4.8214	-2.6
2	4.26	5.1700	5.0765	1.8
3	4.34	5.4300	5.3352	1.7
4	4.42	5.6200	5.5939	0.5
5	4.61	5.7400	5.7780	-0.7
6	*	*	*	*
7	5.07	5.8700	6.0224	-2.6
8	5.42	6.2200	6.1228	1.6

 # 7 cases used, 1 case contains missing value

33. Regression Analysis: F180 versus F90, F28:

Regression equation: F180 = - 0.869 + 1.75 F90 - 0.473 F28

S = 0.182859 R-Sq = 95.4%

Obs	**F90**	**F180**	**Fit**	**X%**
1	4.70	5.2400	5.3882	-2.8
2	5.17	6.4600	6.1634	4.6
3	5.43	6.6000	6.5805	0.3
4	5.62	6.7700	6.8752	-1.5
5	5.74	6.8900	6.9953	-1.5
6	*	*	*	*
7	5.87	7.0400	7.0052	0.5
8	6.22	7.4600	7.4521	0.1

 # 7 cases used, 1 case contains missing value

34. Regression Analysis: F180 versus F90, F28, W/B:

Regression equation: F180 = - 7.81 + 2.41 F90 - 0.157 F28 + 4.56 W/B

S = 0.179638 R-Sq = 96.7%

Obs	**F90**	**F180**	**Fit**	**X%**
1	4.70	5.2400	5.3591	-2.3

2	5.17	6.4600	6.2475	3.3
3	5.43	6.6000	6.6334	-0.5
4	5.62	6.7700	6.8506	-1.2
5	5.74	6.8900	6.9276	-0.5
6	*	*	*	*
7	5.87	7.0400	6.8952	2.0
8	6.22	7.4600	7.5466	-1.2

 # 7 cases used, 1 case contains missing value

35. Regression Analysis: F360 versus F180, F90, F28:

Regression equation: F360 = - 2.48 - 0.357 F180 + 2.74 F90 - 0.538 F28

S = 0.0686388 R-Sq = 99.7%

Obs	F180	F360	Fit	X%
1	5.24	6.3000	6.3065	-0.1
2	6.46	7.1000	7.1064	-0.1
3	6.60	7.7000	7.7264	-0.3
4	6.77	8.2000	8.1438	0.7
5	6.89	8.2800	8.3279	-0.6
6	*	*	*	*
7	7.04	8.4600	8.3836	0.9
8	7.46	8.9600	9.0054	-0.5

 # 7 cases used, 1 case contains missing value

36. Regression Analysis: F360 versus F180, F90, F28, W/B:

Regression equation: F360 = 0.90 - 0.227 F180 + 2.21 F90 - 0.625 F28 - 2.14 W/B

S = 0.0641212 R-Sq = 99.8%

Obs	F180	F360	Fit	X%
1	5.24	6.3000	6.3010	0.0
2	6.46	7.1000	7.1053	-0.1
3	6.60	7.7000	7.7041	0.0
4	6.77	8.2000	8.1417	0.7
5	6.89	8.2800	8.3461	0.8
6	*	*	*	*
7	7.04	8.4600	8.4398	0.2
8	7.46	8.9600	8.9620	0.0

 # 7 cases used, 1 case contains missing value

B-IV) Regression Analysis for Combined Strength Parameters, W/B & Age:

37. Regression Analysis: T28 versus C28:

Regression equation: T28 = - 0.064 + 0.126 C28

S = 0.244952 R-Sq = 98.4%

Obs	C28	T28	Fit	X%
1	35.1	4.1800	4.3524	-4.1
2	39.2	4.9000	4.8599	0.8
3	44.5	5.7600	5.5270	4.0
4	55.8	6.9900	6.9467	0.6
5	62.7	7.6000	7.8086	-2.7
6	66.4	8.4400	8.2784	1.9
7	68.2	8.1400	8.5033	-4.5
8	70.7	9.0800	8.8136	2.9

38. Regression Analysis: T90 versus C28:

Regression equation: T90 = - 1.18 + 0.190 C28

S = 0.719165   R-Sq = 94.0%

Obs	C28	T90	Fit	X%
1	35.1	5.510	5.491	0.3
2	39.2	6.550	6.257	4.5
3	44.5	7.260	7.264	-0.1
4	55.8	9.130	9.408	-3.0
5	62.7	10.170	10.709	-5.3
6	66.4	10.390	11.418	-9.9
7	68.2	12.980	11.758	9.4
8	70.7	12.540	12.226	2.5

39. Regression Analysis: T180 versus C28:

Regression equation: T180 = 0.641 + 0.163 C28

S = 0.331984   R-Sq = 98.2%

Obs	C28	T180	Fit	X%
1	35.1	6.440	6.371	1.1
2	39.2	7.240	7.030	2.9
3	44.5	7.530	7.895	-4.8
4	55.8	9.950	9.737	2.1
5	62.7	10.690	10.855	-1.5
6	66.4	11.360	11.465	-0.9
7	68.2	11.390	11.757	-3.2
8	70.7	12.670	12.160	4.0

40. Regression Analysis: T360 versus C28:

Regression equation: T360 = 1.80 + 0.159 C28

S = 0.453443   R-Sq = 96.6%

Obs	C28	T360	Fit	X%

1	35.1	7.310	7.405	-1.3
2	39.2	8.420	8.048	4.4
3	44.5	9.050	8.895	1.7
4	55.8	10.190	10.695	-4.9
5	62.7	11.210	11.789	-5.2
6	66.4	12.180	12.385	-1.7
7	68.2	12.920	12.670	1.9
8	70.7	13.670	13.064	4.4

41. Regression Analysis: T90 versus C90:

Regression equation: T90 = - 0.626 + 0.133 C90

S = 0.414313 R-Sq = 98.0%

Obs	**C90**	**T90**	**Fit**	**X%**
1	46	5.510	5.537	-0.5
2	54	6.550	6.515	0.5
3	58	7.260	7.161	1.4
4	73	9.130	9.049	0.9
5	82	10.170	10.249	-0.8
6	87	10.390	11.011	-6.0
7	96	12.980	12.230	5.8
8	101	12.540	12.779	-1.9

42. Regression Analysis: T180 versus C180:

Regression equation: T180 = 0.859 + 0.110 C180

S = 0.527625 R-Sq = 95.5%

Obs	**C180**	**T180**	**Fit**	**X%**
1	54	6.440	6.777	-5.2
2	59	7.240	7.329	-1.2
3	63	7.530	7.853	-4.3
4	78	9.950	9.479	4.7
5	84	10.690	10.123	5.3
6	89	11.360	10.698	5.8
7	100	11.390	11.936	-4.8
8	111	12.670	13.076	-3.2

43. Regression Analysis: T360 versus C360:

Regression equation: T360 = - 0.973 + 0.129 C360

S = 0.268794 R-Sq = 98.8%

Obs	**C360**	**T360**	**Fit**	**X%**
1	63	7.3100	7.1762	1.9
2	71	8.4200	8.2092	2.5

3	81	9.0500	9.4006	-3.9
4	89	10.1900	10.5263	-3.3
5	95	11.2100	11.2837	-0.7
6	100	12.1800	11.8929	2.4
7	106	12.9200	12.7159	1.6
8	114	13.6700	13.7451	-0.5

44. Regression Analysis: T28 versus F28:

Regression equation: T28 = - 9.47 + 3.50 F28

S = 0.796243 R-Sq = 83.4%

Obs	F28	T28	Fit	X%
1	4.16	4.180	5.085	-21.6
2	4.26	4.900	5.435	-10.9
3	4.34	5.760	5.715	0.8
4	4.42	6.990	5.995	14.2
5	4.61	7.600	6.659	12.4
6	*	8.440	*	*
7	5.07	8.140	8.268	-1.6
8	5.42	9.080	9.493	-4.5

 # 7 cases used, 1 case contains missing value

45. Regression Analysis: T90 versus F90:

Regression equation: T90 = - 20.9 + 5.43 F90

S = 1.20961 R-Sq = 85.6%

Obs	F90	T90	Fit	X%
1	4.70	5.510	4.622	16.1
2	5.17	6.550	7.176	-9.5
3	5.43	7.260	8.588	-18.2
4	5.62	9.130	9.621	-5.4
5	5.74	10.170	10.273	-1.0
6	*	10.390	*	*
7	5.87	12.980	10.979	15.4
8	6.22	12.540	12.881	-2.7

 # 7 cases used, 1 case contains missing value

46. Regression Analysis: T180 versus F180:

Regression equation: T180 = - 9.95 + 2.92 F180

S = 1.32652 R-Sq = 73.8%

Obs	F180	T180	Fit	X%
1	5.24	6.440	5.339	17.1
2	6.46	7.240	8.899	-22.9

3	6.60	7.530	9.307	-23.6
4	6.77	9.950	9.803	1.5
5	6.89	10.690	10.154	5.0
6	*	11.360	*	*
7	7.04	11.390	10.591	7.0
8	7.46	12.670	11.817	6.7

 # 7 cases used, 1 case contains missing value

47. Regression Analysis: T360 versus F360:

Regression equation: T360 = - 8.72 + 2.43 F360

S = 0.898331 R-Sq = 87.8%

Obs	F360	T360	Fit	X%
1	6.30	7.310	6.607	9.6
2	7.10	8.420	8.554	-1.6
3	7.70	9.050	10.013	-10.6
4	8.20	10.190	11.230	-10.2
5	8.28	11.210	11.425	-1.9
6	*	12.180	*	*
7	8.46	12.920	11.862	8.1
8	8.96	13.670	13.079	4.3

 # 7 cases used, 1 case contains missing value

48. Regression Analysis: F28 versus C28:

Regression equation: F28 = 3.03 + 0.0294 C28

S = 0.221737 R-Sq = 81.1%

Obs	C28	F28	Fit	X%
1	35.1	4.1600	4.0650	2.3
2	39.2	4.2600	4.1838	1.8
3	44.5	4.3400	4.3399	0.0
4	55.8	4.4200	4.6721	-5.7
5	62.7	4.6100	4.8738	-5.7
6	66.4	*	4.9838	*
7	68.2	5.0700	5.0364	0.7
8	70.7	5.4200	5.1090	5.7

 # 7 cases used, 1 case contains missing value

49. Regression Analysis: F90 versus C28:

Regression equation: F90 = 3.77 + 0.0329 C28

S = 0.171305 R-Sq = 90.0%

Obs C28 F90 Fit **X%**

1	35.1	4.7000	4.9235	-4.7
2	39.2	5.1700	5.0566	2.2
3	44.5	5.4300	5.2315	3.7
4	55.8	5.6200	5.6037	0.3
5	62.7	5.7400	5.8297	-1.6
6	66.4	*	5.9529	*
7	68.2	5.8700	6.0118	-2.4
8	70.7	6.2200	6.0932	2.0

7 cases used, 1 case contains missing value

50. Regression Analysis: F180 versus C28:

Regression equation: F180 = 4.39 + 0.0419 C28

S = 0.390530 R-Sq = 73.8%

Obs	C28	F180	Fit	**X%**
1	35.1	5.240	5.859	-11.8
2	39.2	6.460	6.028	6.7
3	44.5	6.600	6.250	5.3
4	55.8	6.770	6.724	0.7
5	62.7	6.890	7.011	-1.8
6	66.4	*	7.168	*
7	68.2	7.040	7.243	-2.9
8	70.7	7.460	7.346	1.5

7 cases used, 1 case contains missing value

51. Regression Analysis: F360 versus C28:

Regression equation: F360 = 4.63 + 0.0600 C28

S = 0.317654 R-Sq = 89.7%

Obs	C28	F360	Fit	**X%**
1	35.1	6.300	6.742	-7.0
2	39.2	7.100	6.985	1.6
3	44.5	7.700	7.303	5.2
4	55.8	8.200	7.981	2.7
5	62.7	8.280	8.392	-1.4
6	66.4	*	8.617	*
7	68.2	8.460	8.724	-3.1
8	70.7	8.960	8.872	1.0

7 cases used, 1 case contains missing value

52. Regression Analysis: F90 versus C90:

Regression equation: F90 = 3.93 + 0.0221 C90

S = 0.178194 R-Sq = 89.2%

Obs	C90	F90	Fit	X%
1	46	4.7000	4.9493	-5.3
2	54	5.1700	5.1114	1.1
3	58	5.4300	5.2186	3.9
4	73	5.6200	5.5315	1.6
5	82	5.7400	5.7305	0.2
6	87	*	5.8567	*
7	96	5.8700	6.0588	-3.2
8	101	6.2200	6.1499	1.1

 # 7 cases used, 1 case contains missing value

53. Regression Analysis: F180 versus C180:

Regression equation: F180 = 4.51 + 0.0271 C180

S = 0.415256 R-Sq = 70.3%

Obs	C180	F180	Fit	X%
1	54	5.240	5.966	-13.8
2	59	6.460	6.102	5.5
3	63	6.600	6.231	5.6
4	78	6.770	6.629	2.1
5	84	6.890	6.787	1.5
6	89	*	6.929	*
7	100	7.040	7.232	-2.7
8	111	7.460	7.512	-0.7

 # 7 cases used, 1 case contains missing value

54. Regression Analysis: F360 versus C360:

Regression equation: F360 = 3.66 + 0.0474 C360

S = 0.267946 R-Sq = 92.7%

Obs	C360	F360	Fit	X%
1	63	6.300	6.657	-5.7
2	71	7.100	7.038	0.9
3	81	7.700	7.476	2.9
4	89	8.200	7.890	3.8
5	95	8.280	8.169	1.3
6	100	*	8.393	*
7	106	8.460	8.696	-2.8
8	114	8.960	9.074	-1.3

 # 7 cases used, 1 case contains missing value

55. Regression Analysis: T28 versus C28, F28:
Regression equation: T28 = - 1.25 + 0.112 C28 + 0.413 F28

S = 0.266879 R-Sq = 98.5%

Obs	C28	T28	Fit	X%
1	35.1	4.180	4.400	-5.3
2	39.2	4.900	4.893	0.1
3	44.5	5.760	5.519	4.2
4	55.8	6.990	6.816	2.5
5	62.7	7.600	7.662	-0.8
6	66.4	8.440	*	*
7	68.2	8.140	8.470	-4.0
8	70.7	9.080	8.891	2.1

 # 7 cases used, 1 case contains missing value

56. Regression Analysis: T28 versus C28, F28, W/B:

Regression equation: T28 = 9.76 + 0.0433 C28 - 0.136 F28 - 11.9 W/B

S = 0.240714 R-Sq = 99.1%

Obs	C28	T28	Fit	X%
1	35.1	4.1800	4.1902	-0.2
2	39.2	4.9000	4.9453	-0.9
3	44.5	5.7600	5.7582	0.0
4	55.8	6.9900	6.8307	2.3
5	62.7	7.6000	7.5771	0.3
6	66.4	8.4400	*	*
7	68.2	8.1400	8.4664	-4.0
8	70.7	9.0800	8.8819	2.2

 # 7 cases used, 1 case contains missing value

57. Regression Analysis: T90 versus C90, F90:

Regression equation: T90 = 2.25 + 0.154 C90 - 0.771 F90

S = 0.341016 R-Sq = 99.1

Obs	C90	T90	Fit	X%
1	46	5.510	5.729	-4.0
2	54	6.550	6.494	0.8
3	58	7.260	7.039	3.0
4	73	9.130	9.068	0.7
5	82	10.170	10.360	-1.9
6	87	10.390	*	*
7	96	12.980	12.543	3.4
8	101	12.540	12.907	-2.9

 # 7 cases used, 1 case contains missing value

58. Regression Analysis: T90 versus C90, F90, W/B:

Regression equation: T90 = 31.1 + 0.0648 C90 - 2.79 F90 - 27.7 W/B

S = 0.337165 R-Sq = 99.3%

Obs	C90	T90	Fit	X%
1	46	5.510	5.735	-4.1
2	54	6.550	6.285	4.0
3	58	7.260	7.261	0.0
4	73	9.130	9.034	1.0
5	82	10.170	10.392	-2.2
6	87	10.390	*	*
7	96	12.980	12.656	2.5
8	101	12.540	12.778	-1.9

 # 7 cases used, 1 case contains missing value

59. Regression Analysis: T180 versus C180, F180:

Regression equation: T180 = - 0.83 + 0.0970 C180 + 0.398 F180

S = 0.503538 R-Sq = 97.0%

Obs	C180	T180	Fit	X%
1	54	6.440	6.456	-0.2
2	59	7.240	7.428	-2.6
3	63	7.530	7.944	-5.5
4	78	9.950	9.441	5.1
5	84	10.690	10.055	5.9
6	89	11.360	*	*
7	100	11.390	11.708	-2.8
8	111	12.670	12.878	-1.6

 # 7 cases used, 1 case contains missing value

60. Regression Analysis: T180 versus C180, F180, W/B:

Regression equation: T180 = 8.0 + 0.0629 C180 + 0.043 F180 - 9.3 W/B

S = 0.558351 R-Sq = 97.2%

Obs	C180	T180	Fit	X%
1	54	6.440	6.438	0.0
2	59	7.240	7.272	-0.4
3	63	7.530	8.043	-6.8
4	78	9.950	9.443	5.1
5	84	10.690	10.189	4.7
6	89	11.360	*	*
7	100	11.390	11.789	-3.5
8	111	12.670	12.736	-0.5

 # 7 cases used, 1 case contains missing value

61. Regression Analysis: T360 versus C360, F360:

Regression equation: T360 = 1.83 + 0.162 C360 - 0.739 F360

S = 0.185897 R-Sq = 99.6%

Obs	C360	T360	Fit	X%
1	63	7.3100	7.4399	-1.8
2	71	8.4200	8.1498	3.2
3	81	9.0500	9.2070	-1.7
4	89	10.1900	10.2553	-0.6
5	95	11.2100	11.1500	0.5
6	100	12.1800	*	*

7	106	12.9200	12.8207	0.8
8	114	13.6700	13.7473	-0.6

 # 7 cases used, 1 case contains missing value

62. Regression Analysis: T360 versus C360, F360, W/B:

Regression equation: T360 = 15.3 + 0.0848 C360 - 0.826 F360 - 14.6 W/B

S = 0.182825 R-Sq = 99.7%

Obs	C360	T360	Fit	X%
1	63	7.3100	7.4102	-1.4
2	71	8.4200	8.1586	3.1
3	81	9.0500	9.1766	-1.4
4	89	10.1900	10.2339	-0.4
5	95	11.2100	11.2500	-0.3
6	100	12.1800	*	*
7	106	12.9200	12.9194	0.0
8	114	13.6700	13.6214	0.3

 # 7 cases used, 1 case contains missing value

VI. EXPERIMENTAL RESULTS: THE OUTPUT EQUATIONS

Regression equations are formulated for:

- Various Compressive strength parameters at different ages and at different W/B ratios.
- Various Tensile strength parameters at different ages and at different W/B ratios.
- Various Flexural strength parameters at different ages and at different W/B ratios.
- The combined strength parameters at different ages and different W/B ratios.

A. Model Equations for Compressive Strengths, W/B & Age

1	C28 versus W/B	C28 = 110 - 139 W/B
2	C90 vs. W/B	C90 = 154 - 201 W/B
3	C180 vs. W/B	C180 = 158 - 199 W/B
4	C360 vs. W/B	C360 = 159 - 174 W/B
5	C90 vs. C28	C90 = -4.89 + 1.44 C28
6	C180 vs. C28	C180 = 1.78 + 1.41 C28
7	C360 vs. C28	C360 = 22.1 + 1.23 C28
8	C90 vs. C28, W/B	C90 = 94.8 + 0.538 C28 - 127 W/B
9	C180 vs. C90, C28	C180 = 9.53 + 1.58 C90 - 0.863 C28
10	C180 vs. C90, C28, W/B	C180 = 10.5 + 1.58 C90 - 0.868 C28 - 1.3 W/B
11	C360 vs. C180, C90, C28	C360 = 21.2 + 0.506 C180 + 0.015 C90 + 0.493 C28
12	C360 vs. C180, C90, C28, W/B	C360= 160 + 0.499 C180 - 0.464 C90 - 0.08 C28 - 179 W/B

B. Model Equations for Tensile Strengths, W/B & Age:

1	T28 vs. W/B	T28 = 13.8 - 17.6 W/B
2	T90 vs. W/B	T90 = 19.8 - 26.7 W/B
3	T180 vs. W/B	T180 = 18.6 - 22.6 W/B
4	T360 vs. W/B	T360 = 19.5 - 22.6 W/B
5	T90 vs. T28	T90 = -0.78 + 1.47 T28
6	T180 vs. T28	T180 = 0.806 + 1.29 T28

7	T360 vs. T28	T360 = 1.96 + 1.26 T28
8	T90 vs. T28, W/B	T90 = 46.7 - 1.95 T28 - 60.9 W/B
9	T180 vs. T90, T28	T180 = 0.932 + 0.163 T90 + 1.05 T28
10	T180 vs. T90, T28, W/B	T180 = -29.6 + 0.636 T90 + 2.57 T28 + 39.7 W/B
11	T360 vs. T180, T90, T28	T360 = 2.37 - 0.083 T180 + 0.434 T90 + 0.726 T28
12	T360 vs. T180, T90, T28, W/B	T360= 47.8 + 1.03 T180 - 0.468 T90 - 2.77 T28 - 60.4 W/B

C. Model Equations for Flexural Strengths, W/B & Age:

1	F28 vs. W/B	F28 = 6.32 - 4.22 W/B
2	F90 vs. W/B	F90 = 7.44 - 4.70 W/B
3	F180 vs. W/B	F180 = 9.10 - 6.10 W/B
4	F360 vs. W/B	F360 = 11.3 - 8.49 W/B
5	F90 vs. F28	F90 = 1.20 + 0.941 F28
6	F180 vs. F28	F180 = 1.23 + 1.17 F28
7	F360 vs. F28	F360 = 0.37 + 1.62 F28
8	F90 vs. F28, W/B	F90 = 8.58 - 0.182 F28 - 5.46 W/B
9	F180 vs. F90, F28	F180 = -0.869 + 1.75 F90 - 0.473 F28
10	F180 vs. F90, F28, W/B	F180 = -7.81 + 2.41 F90 - 0.157 F28 + 4.56 W/B
11	F360 vs. F180, F90, F28	F360 = -2.48 - 0.357 F180 + 2.74 F90 - 0.538 F28
12	F360 vs. F180, F90, F28, W/B	F360= 0.9 - 0.227 F180 + 2.21 F90 - 0.625 F28 - 2.14 W/B

D. Model Equations for the Combined Parameters:

1	T28 vs. C28	T28 = -0.064 + 0.126 C28
2	T90 vs. C28	T90 = -1.18 + 0.190 C28
3	T180 vs. C28	T180 = 0.641 + 0.163 C28
4	T360 vs. C28	T360 = 1.80 + 0.159 C28
5	T90 vs. C90	T90 = -0.626 + 0.133 C90
6	T180 vs. C180	T180 = 0.859 + 0.110 C180
7	T360 vs. C360	T360 = -0.973 + 0.129 C360
8	T28 vs. F28	T28 = -9.47 + 3.50 F28
9	T90 vs. F90	T90 = -20.9 + 5.43 F90
10	T180 vs. F180	T180 = -9.95 + 2.92 F180
11	T360 vs. F360	T360 = -8.72 + 2.43 F360
12	F28 vs. C28	F28 = 3.03 + 0.0294 C28
13	F90 vs. C28	F90 = 3.77 + 0.0329 C28
14	F180 vs. C28	F180 = 4.39 + 0.0419 C28
15	F360 vs. C28	F360 = 4.63 + 0.0600 C28
16	F90 vs. C90	F90 = 3.93 + 0.0221 C90
17	F180 vs. C180	F180 = 4.51 + 0.0271 C180
18	F360 vs. C360	F360 = 3.66 + 0.0474 C360
19	T28 vs. C28, F28	T28 = -1.25 + 0.112 C28 + 0.413 F28
20	T28 vs. C28, F28, W/B	T28 = 9.76 + 0.0433 C28 - 0.136 F28 - 11.9 W/B
21	T90 vs. C90, F90	T90 = 2.25 + 0.154 C90 - 0.771 F90
22	T90 vs. C90, F90, W/B	T90 = 31.1 + 0.0648 C90 - 2.79 F90 - 27.7 W/B
23	T180 vs. C180, F180	T180 = -0.83 + 0.097 C180 + 0.398 F180
24	T180 vs. C180, F180, W/B	T180 = 8.0 + 0.0629 C180 + 0.043 F180 - 9.3 W/B
25	T360 vs. C360, F360	T360 = 1.83 + 0.162 C360 - 0.739 F360
26	T360 vs. C360, F360, W/B	T360 = 15.3 + 0.0848 C360 - 0.826 F360 - 14.6 W/B

VII. DISCUSSION ON THE PROJECT RESULTS

These equations have been formulated with maximum accuracy. The following proofs support this statement:

Proof - 1: The tables of Regression Analysis show: the percentage variations (X) between actual values and equation fit values are nominal, which proves these Model equations are reliable (chapter 2.3.1).

Proof - 2: R-square values are at a reasonably higher side (between 61.7% of eq.30 and 99.9 % of eq.12), which shows these regression equations fit to best of the data (chapter 2.3.1).

Proof - 3: Standard deviation values range at lower values (between 0.06 of eq.36 and 5.54 of eq.6), which shows these regression equations predict the best of the response variables (chapter 2.3.1).

Hence, these model equations are proved to be accurate and reliable for Industry use.

A. Application of The Project Output Equations in Rigid Pavement

- F28 (Flexural strength at 28 days), C28 (Compressive strength at 28 days), T28 (Tensile strength at 28 days) are the important design inputs required for the design process of Rigid pavements, as per AASHTO and IRC.
- C90, T90, F90; C180, T180, F180; C360, T360, F360 - are also formulated, because they are required to assess the serviceability of the rigid pavements at later ages.

B. Knowing Unknowns from The Output Equations

1) *From the 2-variable equations:* If a variable is known, then an unknown variable can be found.
   - For a W/B ratio: C28, C90, C180, C360 can be known. (Eq. 1, 2, 3, 4)
   - For a W/B ratio: T28, T90, T180, T360 can be known. (Eq. 13, 14, 15, 16)
   - For a W/B ratio: F28, F90, F180, F360 can be known. (Eq. 25, 26, 27, 28)
   - If C28 is known, then C90, C180, C360 can be found. (Eq. 5, 6, 7)
   - If C28 is known, then T28, T90, T180, T360 can be found. (Eq. 37, 38, 39, 40)
   - If C28 is known, then F28, F90, F180, F360 can be found. (Eq. 48, 49, 50, 51)
   - If T28 is known, then T90, T180, T360 can be found. (Eq. 17, 18, 19)
   - If F28 is known, then F90, F180, F360 can be found. (Eq. 29, 30, 31)

Vice versa is also possible, for all the equations.

2) *From the 3-variable equations:* An unknown variable can be found, if any 2 variables are known.
3) *From the 4-variable equations:* An unknown variable can be found, if any 3 variables are known.
4) *From the 5-variable equations:* An unknown variable can be found, if any 4 variables are known.

VIII. SUMMARY

The Model equations for the strength parameters of High-volume fly ash concrete at various ages and various W/B ratios are formulated (Chapter 6.0). A simplified list of 31 simple equations out of the 62 project-formulated Model equations, which are useful in the HVFA mixed concrete rigid pavements, is given below in Table V:

TABLE V
LIST OF SIMPLE EQUATIONS

S. No.	Parameters	Equation	Eq. ref. from Chapter VI
1	C28 vs. W/B	C28 = 110 - 139 W/B	1
2	C90 vs. W/B	C90 = 154 - 201 W/B	2
3	C180 vs. W/B	C180 = 158 - 199 W/B	3
4	C360 vs. W/B	C360 = 159 - 174 W/B	4
5	C90 vs. C28	C90 = -4.89 + 1.44 C28	5
6	C180 vs. C28	C180 = 1.78 + 1.41 C28	6
7	C360 vs. C28	C360 = 22.1 + 1.23 C28	7
8	T28 vs. W/B	T28 = 13.8 - 17.6 W/B	13
9	T90 vs. W/B	T90 = 19.8 - 26.7 W/B	14

S. No.	Parameters	Equation	Eq. ref. from Chapter VI
10	T180 vs. W/B	T180 = 18.6 - 22.6 W/B	15
11	T360 vs. W/B	T360 = 19.5 - 22.6 W/B	16
12	T90 vs. T28	T90 = -0.78 + 1.47 T28	17
13	T180 vs. T28	T180 = 0.806 + 1.29 T28	18
14	T360 vs. T28	T360 = 1.96 + 1.26 T28	19
15	F28 vs. W/B	F28 = 6.32 - 4.22 W/B	25
16	F90 vs. W/B	F90 = 7.44 - 4.70 W/B	26
17	F180 vs. W/B	F180 = 9.10 - 6.10 W/B	27
18	F360 vs. W/B	F360 = 11.3 - 8.49 W/B	28
19	F90 vs. F28	F90 = 1.20 + 0.941 F28	29
20	F180 vs. F28	F180 = 1.23 + 1.17 F28	30
21	F360 vs. F28	F360 = 0.37 + 1.62 F28	31
22	T28 vs. C28	T28 = -0.064 + 0.126 C28	37
23	T90 vs. C28	T90 = -1.18 + 0.190 C28	38
24	T180 vs. C28	T180 = 0.641 + 0.163 C28	39
25	T360 vs. C28	T360 = 1.80 + 0.159 C28	40
26	T28 vs. F28	T28 = -9.47 + 3.50 F28	44
27	F28 vs. C28	F28 = 3.03 + 0.0294 C28	48
28	F90 vs. C28	F90 = 3.77 + 0.0329 C28	49
29	F180 vs. C28	F180 = 4.39 + 0.0419 C28	50
30	F360 vs. C28	F360 = 4.63 + 0.0600 C28	51
31	T28 vs. C28, F28	T28 = -1.25 + 0.112 C28 + 0.413 F28	55

IX. SCOPE OF FURTHER WORK

In the course of further work, the Nomograms can also be created for different combinations of the parameters mentioned below:

1) *Different Quantities of Concrete constituents:* Cement, Coarse aggregate, Fine aggregate, Water, Superplasticizer, Fly ash, GGBFS, Copper slag.
2) *Various Grades of Cement:* 33G, 43G, 53G, and others.
3) *Various Properties of Aggregates:* Specific Gravity, Impact Value, Aggregate Crushing Value, Flakiness, 10% Fines Value, Fineness Modulus.
4) *Various Properties of Fly Ash:* Loss on Ignition, Grade of Fly Ash
5) *Concrete Grades:* M15, M20, M25, M30, M35, M40, M45, M50, M60 etc.
6) *Properties of Concrete:* Modulus of Elasticity, Slump value, Compressive Strength, Tensile Strength, Flexural Strength.
7) *Different Curing Temperatures of Concrete*

X. CONCLUSIONS

The formulated Model equations are reliable for use in rigid pavements and the concrete industry using the HVFAC. (as proved in Chapter VII).

XI. ACKNOWLEDGMENT

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REFERENCES

[1] www.minitab.com
[2] www.barbecuejoe.com/scan.htm
[3] www.hotmath.com
[4] David J Carrejo and Jill Marshall, "What is mathematical modelling?", Mathematics Education Research Journal, University of Texas, Vol-19, 2007.
[5] www.deadrockings.com

[6] ASTM: C-618, "Specification for coal fly ash and raw or calcined natural pozzolan for use as a mineral admixture in concrete", American Society for Testing & Materials, 2001.

[7] IS:3812, "Specification of fly ash for use as pozzolana & admixture", Bureau of Indian Standards, 1999.

[8] IS:10262, "Concrete mix design", Bureau of Indian Standards, 2009.

[9] IS:456, "Specification for plain & RCC concrete", Bureau of Indian Standards, 2000.

[10] IS:516, "Methods of tests for strength of concrete", Bureau of Indian Standards, 2002.

[11] IS:5816, "Test method for splitting tensile strength of concrete", Bureau of Indian Standards, 1999.

[12] BS:1881 Part-117, "Method for determination of tensile Splitting strength of concrete", British Standards Institution, 1989.

[13] IRC:68, "Guidelines on cement fly ash concrete for rigid pavement construction", Indian Roads Congress, 1976.

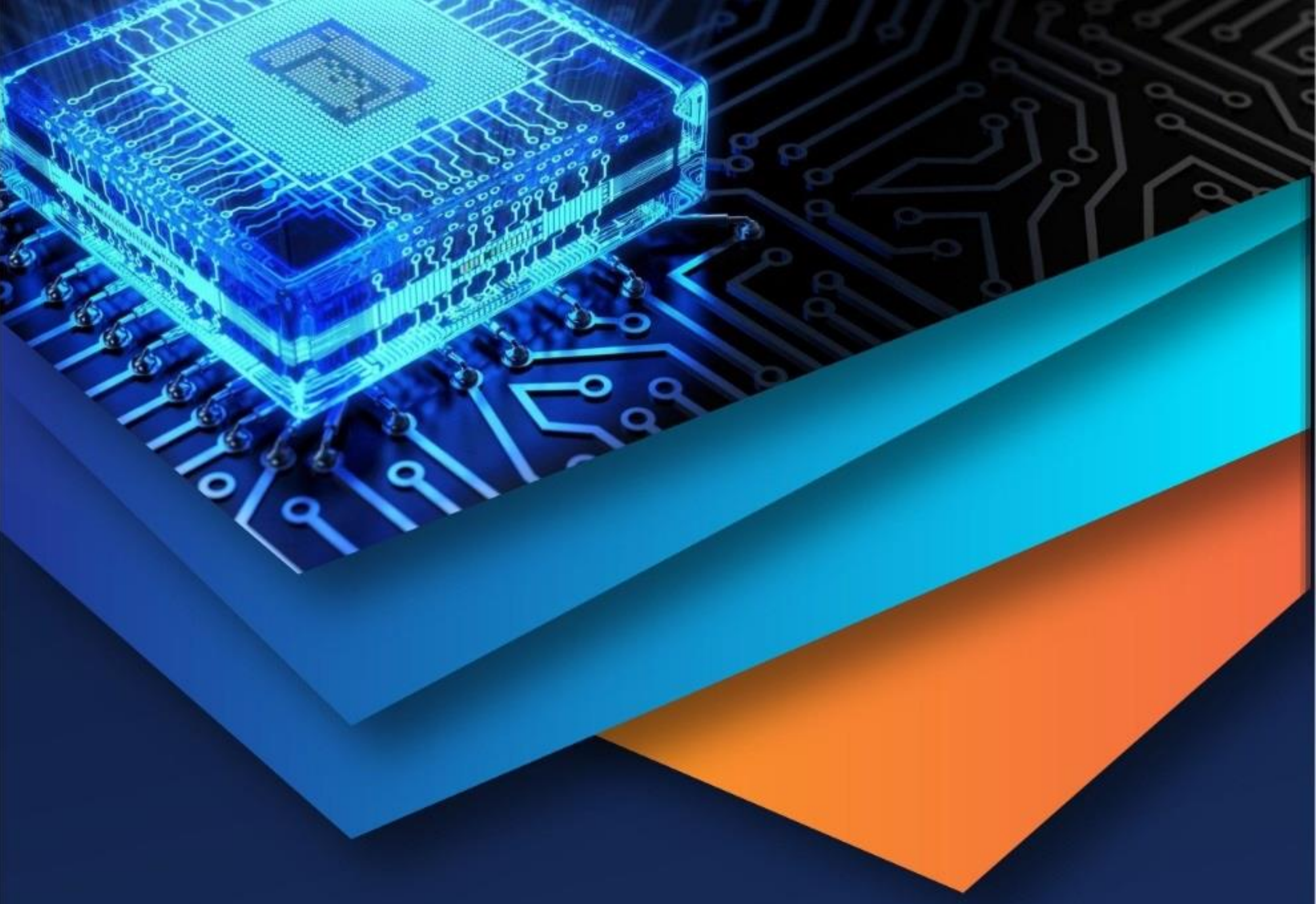
[14] Malhotra V M and Mehta P K, "High-performance, high-volume fly ash concrete", Supplementary cementing materials for sustainable development Inc., Ottawa, Canada, 2002, pp.101.

[15] Mehta P K, "High-performance, high-volume fly ash concrete for sustainable development", International workshop on sustainable development and concrete technology.

[16] Malhotra V M and Ramezanianpour A A, "Fly ash in concrete", CANMET, Canada, 1994.

[17] Bhanumathidas N and Kalidas N, "Fly ash for sustainable development", Ark Communications, Chennai, 2002.

[18] Ash utilization division of NTPC, "Fly ash for Cement concrete - Resource for high strength & durability of structures at lower cost", NTPC, May 2007.



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